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From:

PHASED INTRODUCTION OF FUEL CELLS INTO A CLASS 8 TRACTOR

INTERIM REPORT

SwRI Project No. 03983
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Prepared For

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3.10.1.1.2.10 Baseline Performance Determinations

SwRI was tasked to perform baseline performance determinations which were to encompass testing of the Class 8 tractor under repeatable conditions. After the vehicle was broken in, the first test was to be a coastdown test to determine vehicle constants, such as aerodynamic and rolling resistance factors. Acceleration tests were to be performed at truck empty weight plus a cargo weight, to obtain acceleration data, hill climb, and startability on grade.

This section documents the baseline performance testing for the SunLine Transit Peterbilt 385 tractor. These tests include coastdowns to determine drag coefficients and acceleration runs with five different fuels. The fuels used in these determinations, listed in Table 3.10.1.1.2.10 Test Fuels, were EPA Certification D2 Diesel, California ultra-low sulfur diesel fuel (ULSDF), JP-8 (military jet fuel), synthetic F-T gas-to-liquid (FT GTL) diesel fuel and Biodiesel (B20 blend in ULSDF). SwRI performed testing January 2002.

Peterbilt Motors Company manufactured the SunLine tractor, VIN number 1XP-GD58X-2D581457, in December 2001. The truck had a GVWR of 46,160 pounds, and was powered with a 2001 model year Cummins ISL 8.9L, I-6, turbo-charged, diesel engine rated at 330 bhp at 2,100 rpm. It was equipped with a 10-speed manual transmission and super single tires. SwRI broke in the truck by driving it on the highway with a load. The odometer showed that the truck had accumulated 3,348 miles with 65.1 engine hours before performance testing.

3.10.1.1.2.10.1 Coastdown Test Procedures

The objective of this work was to generate baseline aerodynamic and rolling drag coefficient data from a Peterbilt tandem-axle tractor and trailer. The Peterbilt 385 tractor pulled a flatbed trailer with concrete blocks for ballast for a total truck/trailer weight of 53,220 pounds. Figure 3.10.1.1.2.10-1, Tractor Trailer with Load, depicts the tractor-trailer combination with the concrete block load. The truck was taken to a stretch of road two hours south of San Antonio and run between the towns of Los Angles, TX and Fowlerton, TX. This area was chosen for its low traffic and level, smooth roads. Following SAE procedure J2263 the tractor and trailer were taken through a series of runs in alternating directions with four runs in one direction and four runs in the opposite direction until a total of forty runs were completed. Time, speed, and weather conditions were all recorded and averaged to arrive at a drag coefficient Cd of 1.01 for the truck and trailer. From this Cd the road load can be calculated, providing more accurate parameters for the computer model.



Figure 3.10.1.1.2.10-1, Tractor-Trailer with Load

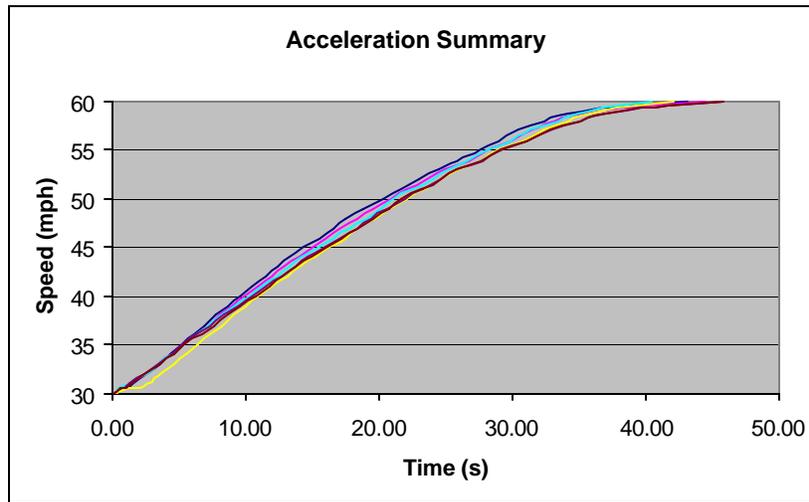
3.10.1.1.2.10.2 Acceleration Test Procedures

The objective of this work was to compare the baseline performance of the Peterbilt 385 tractor and loaded trailer running Certification EPA No. 2 diesel to the five other fuels listed in Table 3.10.1.1.2.10. These five fuels were stored in separate ten-gallon fuel tanks that were placed behind the cab, as shown in Figure 3.10.1.1.2.10-2, Test Fuel Tank Setup. The test fuel tank directly replaced the OEM fuel tank on the tractor and allowed SwRI to maintain the OEM fuel delivery system on the truck. In order to prevent cross-contamination between the fuels, a test fuel tank was purchased for each fuel, and the fuel system was flushed out with the new test fuel after each test fuel was run.

For this series of tests we followed SAE procedure J-1491. This entailed taking the tractor-trailer through a series of six runs in opposing directions, accelerating from 30 to 60 mph. Since the tractor has a ten speed manual transmission, and driver shifting inconsistency could adversely affect the test, the truck was accelerated in a single gear for these tests. Ninth gear was selected to run this test because of its capability to operate over the speed range, eliminating driver error associated with shifting the transmission. Figure 3.10.1.1.2.10-3 Acceleration Runs, summarises the acceleration runs with the test fuels with six runs averaged together for each fuel. The graph shows that there are only small differences in performance between the five test fuels. This indicates that environmentally friendly fuels, such as the Fischer Tropsch gas to liquid fuel can be used without penalizing performance.



Figure 3.10.1.1.2.10-2, Test Fuel Tank Setup



**Figure 3.10.1.1.2.10-3 Acceleration Runs
Table 3.10.1.1.2.10 Test Fuels**

Fuel Name	VRD Fuel Code	Fuel Code
Cert. EPA No. 2 Diesel	VE-0271	CL01-1005

JP-8 Aviation Diesel	VE-0269	CL01-1004
20% Biodiesel Blend	VE-0274	CL01-989
ARCO ECD-1 Diesel	VE-0270	CL01-985
Fischer-Tropsch GTL Synthetic Diesel	VE-0273	CL01-1025

In addition to the 30 to 60 mph tests, a set 0 to 60 mph tests were run under the same testing regime using the diesel fuel in the OEM fuel tank. These runs were not used in the fuel comparison since the shifting uncertainty creates a situation where the data is more of a test of the driver, and not the individual fuel. The results of these tests show an average 0 to 60 mph acceleration time of 65.2 seconds. After the truck and transmission are more broken in, a better 0 to 60 time might be possible due to better shift times. At the time of testing, with a relatively new transmission, shift time between gears was up to 2 seconds.

3.10.1.1.2.11 Baseline Emissions Testing

The objective of the baseline emissions testing was to generate baseline fuel economy and exhaust emissions data from the SunLine tandem-axle tractor. Exhaust emissions test data was generated using the step-by-step test plan summarized in Table 3.10.1.1.2.11-1, Baseline Emissions Test Plan.

Peterbilt Motors Company manufactured the SunLine tractor, VIN number 1XP-GD58X-2D581457, in December of 2001. The tractor had a GVWR of 46,160 pounds, and was powered with a 2001 model year Cummins ISL 8.9L, I-6, turbo-charged, diesel engine rated at 330 bhp at 2,100 rpm. It was equipped with a 10-speed manual transmission and super single tires. Prior to testing, SwRI broke in the truck by driving it on the highway with a concrete block load. The odometer showed that the truck had accumulated 3,024 miles before testing, with 50.6 engine hours.

The test cycle used in this program was the EPA Urban Dynamometer Driving Schedule (UDDS) for Heavy Duty Vehicles. The test cycle, depicted in Figure 3.10.1.1.2.11-1, Urban Dynamometer Driving Schedule, covered a distance of 5.5 miles over 1,060 seconds. Tests were run in accordance with the procedure outlined in Table 3.10.1.1.2.11-1 and were repeated three times for five Diesel fuels; D2 Diesel which

meets EPA certification specifications, JP-8, Arco ECD-1, a 20 percent Biodiesel blended with ECD-1 (B20), and a Fischer Tropsch fuel. These fuels and their corresponding test numbers and sequence is shown in Table 3.10.1.1.2.11-1 Emissions Test Fuels. For each set of tests, the engine was fueled from a 55-gallon drum of the appropriate test fuel. Hot return fuel from the engine was routed through a heat exchanger to prevent the fuel in the drum from heating. In addition, a purge routine was used during fuel changes, to eliminate the previous fuel from the system. Fuel analysis results are given in Appendix C, Test Fuel Properties.

The total dynamometer simulated inertia (test weight) of the tractor was 48,300 pounds. Inertia simulation on the SwRI heavy-duty chassis dynamometer, shown in Figure 3.10.1.1.2.11-2, Heavy Duty Chassis Dynamometer, uses mechanical flywheels coupled to the driven rolls. Using the EPA Recommended Procedure, the total theoretical road load at 50 mph was 103.6 hp, based on a calculated rolling resistance of 60.38 hp and aerodynamic influences of 43.23 hp.

The fuel consumption during the test was measured to provide an accurate baseline for comparison with the modified vehicle. The test procedure for obtaining fuel mileage is done during the emissions testing. The data from the emissions testing was processed and fuel economy was calculated using the carbon balance method.

During the cycle shown in Figure 3.10.1.1.2.11-1, gaseous and particulate emission measurements were made using procedures outlined in an 1979 EPA report titled "Recommended Practice for Determining Exhaust Emissions from heavy-duty Vehicles Under Transient Conditions." Emissions of total hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO₂), and oxides of nitrogen (NO_x) were measured during transient testing. Following diesel engine testing protocols, total hydrocarbon and NO_x concentrations were continuously monitored in the dilute exhaust over each test and the integrated results used in computing emissions. NO_x correction factors for engine intake air humidity were applied as specified in the transient Federal Testing Procedure (FTP) for diesel fueled engines. Nondispersive infrared (NDIR) instruments determined the concentrations of CO and CO₂ in the proportional dilute exhaust bag samples. Concentrations of HC, CO, CO₂, and NO_x were processed along with Constant Volume Sampling (CVS) flow parameters and vehicle operating parameters to compute mass emissions on the basis of distance (g/mi.). These computations are based on equations specified in the Code of Federal Regulations (CFR). Particulate emissions were measured using dilute sampling techniques as specified in the transient Federal Testing Procedure (FTP) for diesel fueled engines.

Particulate emissions were measured using dilute sampling techniques as specified in the transient FTP for diesel-fueled engines. The PM filter media used was 90 Millimeters (mm) Pallflex T60A20. The CVS flow rate was nominally 2,000 scfm and single dilution PM sampling techniques were used to maximize filter mass loading.

Table 3.10.1.1.2.11-1 Baseline Emissions Test Plan

Step	Description
1	Perform emission measurement system and chassis dynamometer system checks and calibrations.
2	Set system inertia to 48,300 pounds. Install the tractor on the heavy-duty chassis dynamometer.
3	Isolate on-board fuel system, and provide fuel from a drum containing the first specified fuel in Table 2.
4	Perform coast downs to establish as-installed system rolling resistance load as a function of vehicle speed. Establish dynamometer load to achieve required simulated road load. Set up to acquire information necessary to process emission test-related data.
5	Perform practice-driving cycles to check dilution tunnel settings and instrument ranges.
6	Perform the following test sequence, measuring emissions of HC, CO, CO ₂ , NO _x , and PM. <ol style="list-style-type: none">Set road load at 50 mphRun prep “Heavy-Duty Urban Dynamometer Driving Schedule” to warm engine to stabilized conditions15-minute engine-off soakRun first hot-start test for specified fuel15-minute engine-off soakRun second hot-start test for specified fuel15-minute engine-off soakRun third hot-start test for specified fuelDisconnect fuel and connect to remaining fuels specified in Table 2Run truck at idle until 4 gallons of fuel is purged into waste containerOperate vehicle to 50 mph to verify load settingRepeat steps b-k for remaining fuels
7	Remove tractor from chassis dynamometer.
8	Summarize and report results.



Figure 3.10.1.1.2.11-2, Heavy Duty Chassis Dynamometer

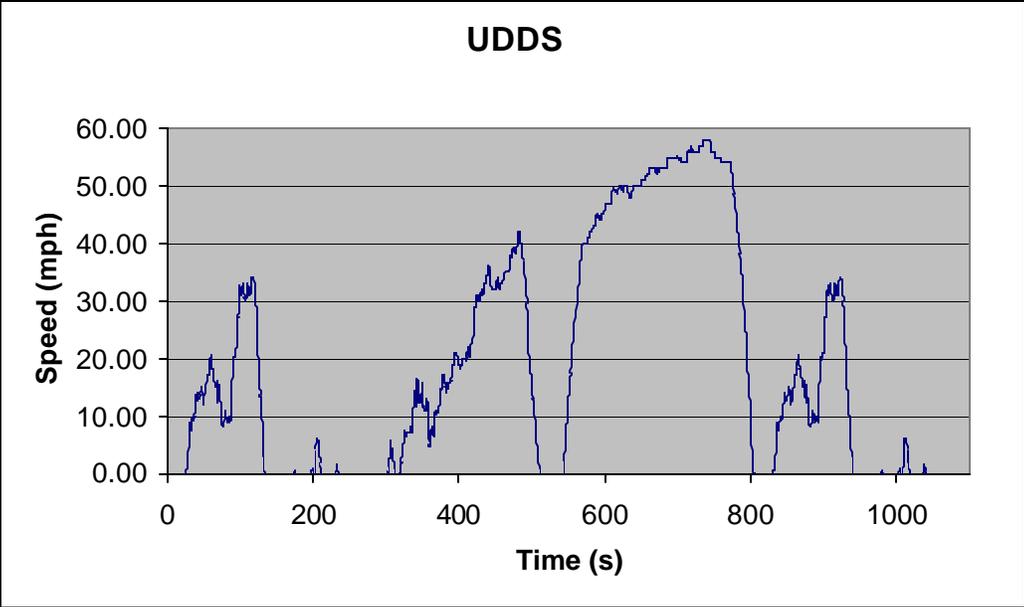


Figure 3.10.1.1.2.11-1, Urban Dynamometer Driving Schedule

Table 3.10.1.1.2.11-1 Emissions Test Fuels

Test No.	Fuel Name	VRD Fuel Code	Fuel Code
EPA-H1	Cert. EPA No. 2 Diesel	VE-0271	CL01-1005
EPA-H2			
EPA-H4*			
JP8-H1	JP-8 Aviation Diesel	VE-0269	CL01-1004
JP8-H2			
JP8-H3			
B20-H1	20% Biodiesel Blend	VE-0274	CL01-989
B20-H2			
B20-H3			
ECD-H1	ARCO ECD-1 Diesel	VE-0270	CL01-985
ECD-H2			
ECD-H3			
FT-H1	Fischer-Tropsch GTL Synthetic Diesel	VE-0273	CL01-1025
FT-H2			
FT-H3			

***EPA-H3 test void due to error in PM measurement**

Table 3.10.1.1.2.11-2 Baseline Emissions Test Summary, summarizes the exhaust emission and fuel economy results from the baseline tests performed at SwRI. Exhaust emission results are presented in units of grams per mile. Individual test data may be viewed in Attachment B.

Table 3.10.1.1.2.11-2 Baseline Emissions Test Summary

2001 SunLine Peterbilt — Baseline Diesel Performance							
SwRI Project No. 03-03983.04.211 updated 17 January 2002							
Composite Results All Fuels							
Inertia Test Weight = 48,300 LBS							
	Test	HC	CO	NOx	PM	CO ₂	MPG
	Fuel	g/mi	g/mi	g/mi	g/mi	g/mi	
	EPA CERT	1.06	3.1	14.3	0.68	1,835	5.5

	JP8	1.35	3.0	12.8	0.56	1,761	5.4
	ECD-1	1.07	3.0	13.1	0.60	1,742	5.6
	B20	1.03	2.8	13.4	0.56	1,797	5.4
	FT-GTL	0.61	2.7	12.2	0.51	1,703	5.3
% Deviation from Diesel Fuel Meeting EPA Cert. Specifications*							
	Test	HC	CO	NOx	PM	CO ₂	
	Fuel	%	%	%	%	%	
	JP8	27.5	-4.8	-10.5	-18.1	-4.0	
	ECD-1	0.4	-3.5	-8.2	-11.6	-5.1	
	B20	-2.6	-10.7	-6.3	-17.0	-2.1	
	FT-GTL	-42.4	-11.6	-14.3	-24.6	-7.2	
	* -% signifies decrease in emissions from cert. Fuel						

The fuels used to provide baseline exhaust emission data were EPA Certification D2 Diesel, California ultra-low sulfur diesel fuel (ULSDF), JP-8 (military jet fuel), synthetic F-T gas-to-liquid (FT GTL) diesel fuel and Biodiesel (B20 blend in ULSDF). Fuel property data are summarized in Appendix C, Test Fuel Properties. The test methods and data for the fuels are provided in Table C-1. The test methods and data for the biodiesel B100 fuel used to make the biodiesel B20 blend (with ARCO ECD-1) is provided in Table C-2.

The EPA Diesel #2 Certification fuel is used to certify engine exhaust emission level compliance with legal limits at the time of manufacture of the engine. This fuel (coded CL01-1005) has a 50 cetane number, 0.8500 Kg/m³ density, 345 ppm sulfur, and 34.1 wt% aromatic.

The California ULSDF is manufactured as an ARCO ECD-1 environmentally clean diesel fuel that is CARB (California Air Resources Board) low sulfur fuel equivalent. It would be compliant if the aromatic content were below 10 percent. This fuel (coded CL01-985) has a 57 cetane number, 0.8207 Kg/m³ density, 7 ppm sulfur, and 19 wt% aromatic. The lower cetane number value of 51.7 by SwRI Ignition Quality Tester (IQT) is believed to be the more accurate value for this fuel and agrees well with the manufacturer's value and the cetane index values.

Age Refining, Inc., in San Antonio, TX manufactured the JP-8 aviation turbine fuel to MIL-DTL-83133 specification requirements. This fuel (coded CL01-1004) has a 47 cetane number, 0.7947 Kg/m³ density, 55 ppm sulfur, and 20 wt% aromatic. The lower cetane number value of 44.9 by SwRI Ignition Quality Tester (IQT) is believed to be the more accurate value for this fuel and agrees well with the cetane index values. The viscosity of this fuel is below the engine manufacturer's minimum recommended guidance value.

The synthetic Fischer Tropsch GTL diesel fuel was manufactured at the Shell Bintulu refinery. This No. 2 diesel fuel (CL01-1025) has a >75 cetane number, 0.7839 Kg/m³ density, 0.6 ppm sulfur, and 0 wt% aromatic. A lubricity additive, Infinium R690 at 250mg/L treat rate, was added to this fuel to improve the lubricity to reduce wear of fuel wetted, load-carrying components of the engine/fuel system.

The Biodiesel B20 blend was prepared at SwRI by adding 20 V% biodiesel (CL01-1003, made from used cooking oil) to the ARCO ECD-1 diesel fuel (CL01-985). This biodiesel B20 blend has a 53.5 cetane number, 0.8330 Kg/m³ density, 12 ppm sulfur, and 19.3 wt% aromatics. The aromatics data suggests that the biodiesel portion of B20 does not participate in the hydrocarbon analysis when ASTM D 2425 procedure is employed. The cetane number value of 53.5 by SwRI Ignition Quality Tester (IQT) agrees well with the D 613 cetane number and the cetane index values. General guidance for use of biodiesel B20 blends in California is for the biodiesel not to degrade important properties related to diesel fuel quality and exhaust emissions. Since biodiesel made from used frying oils tend to have higher cetane numbers than those for soy bean oil derived biodiesel, B20 biodiesel blends with CARB diesel are expected to be more acceptable for use in California.